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An evaluation of Chinese Wind Turbine Manufacturers using the enterprise niche theory

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ABSTRACT

With support from the Chinese government, the Chinese wind power generation industry is experiencing rapid development. The quick growth of the wind power generation industry has promoted the development of the Chinese wind turbine manufacturing industry. Similarly, the quantity and the productivity of the local Chinese Wind Turbine Manufacturers (WTMs) have also undergone a quick and significant expansion. This is resulting in an increase in competition amongst the WTMs in China. Being relatively new, this creates a fertile environment for local Chinese WTMs that is ripe for study and analysis. Based on the niche theory of industrial ecosystem and enterprise, this paper investigates the Chinese wind turbine manufacturing industry, and proposes a wind turbine manufacturing industry ecosystem model and a WTMs' ecological niche evaluation index system (WENEIS). Use is made of a catastrophe theory model evaluation method to evaluate the ecological niche status of the 6 main local Chinese WTMs selected and a spider diagram is established to compare the status of the different enterprises' ecological niche. The proposed WENEIS aids WTMs in finding the competitive advantage and disadvantage factors for their development, as well as providing a valuable reference for the WTMs to improve their business environment and to formulate their competitive strategy in the future.

Contents

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1. Introduction

Before 2005, there were only a few local Chinese Wind Turbine Manufacturers (WTMs), all with small scale and dated technology, and China was forced to rely on imported turbines for wind energy projects. Since 2005, The Chinese government has been active in formulating a series of interrelated policies to promote wind power development and encourage the development and construction of wind energy projects [1]. It is clear that wind power will occupy an important position in the future Chinese power and energy mix [2]. In particular, the rapid development of the wind power generation industry has had a significant effect on the increased market demand for the wind turbines. Up to the end of 2009, China had installed 21,544 wind turbine units with a total capacity 25,805 MW. This number has overtaken Germany, and China now has the second largest number of wind turbines in the world, and the number of the WTMs has increased to more than 80 [3]. According to the manufacture capacity expansion plan for Chinese WTMs, the effective output of WTMs has increased from 11,000 MW in 2009 to 19,000 MW in 2010, whereas the Chinese market demand only increased from 8120 MW to 10,560 MW for the same periods [4]. Hence we have a developing trend where the manufacture of wind turbines is surpassing market demand and contributing to a complex manufacturing environment and an increase in competition amongst the local Chinese WTMs. This calls into question the suitability of the local WTMs in the Chinese energy market and provides a good reason to research and analyze the wind power generation industry. Using the industrial ecosystem and enterprise niche theory, this paper constructs a wind turbine manufacturing industry ecosystem model and a WTMs' ecological niche evaluation index system (WENEIS) to study the WTMs' ability to coordinate both resource supply and market demand entities, and to manage the degree of adaptation and functional relationship between the WTMs and the external environment involving the social, economic and policy environment. Subsequently, a catastrophe theory model evaluation method is used to conduct quantitative assessments of the ecological niche status of the 6 main local Chinese WTMs.

2. Industrial ecosystem and enterprise niche

2.1. Industrial ecosystem

Since Baldin's ecological economics theory of the 1960s [5], some researchers have proposed different types of natural ecosystem biological theories that could be applied in the fields of economics and management.

As a biology concept, an ecosystem represents a dynamic and balanced system consisting of biological communities and the physical environment upon which those communities rely [6]. In this paper, we define industrial ecosystem as a dynamically balanced system where the enterprises and the external environment coexistence derives from the interaction and interdependency between the enterprises and the external environment under certain time and space conditions. Introducing the industrial ecosystem may help to clarify the relationships amongst enterprises in the industry and to analyze the enterprise's ability to coordinate with the external environment.

2.2. Enterprise niche

Ecological niche is an important concept in contemporary ecology. Grinnel was the first to describe the term as "the ultimate distribution unit occupied by different species" [7]; Elton considered ecological niche as the status in the biological environment and the relationships with the food and the natural enemies [8]. In the late 1950s, Hutchinson considered ecological niche as the selected range of species to survive in the specific environment variables including temperature, humidity, nutrition, etc. [9]. Similarly, other ecology experts gave different definitions from various perspectives and enriched the theory.

For the enterprise niche researchers generally have two typical views namely:

- From the view of the enterprise population, Hannan and Freeman defined the enterprise niche as multi-dimensional resource space occupied by enterprises in strategic environment [10].
- From the view of the individual enterprises, Baum et al. considered that enterprise niche is a status that results from the interactive matching between the enterprise and external environment, and reflects a company's characteristics of resource demand and production capacity [11].

The first point of view assumes that the enterprise population is an elementary unit in enterprise niche, whereas the later point of view assumes that the individual enterprise is an elementary and fundamental unit. However, both points of view focus on the correlation between the enterprises and the external environment. The presence of enterprise niche reflects the fact that researchers are beginning to accept the enterprise as a non-isolated individual, and to pay more attention to the iterative reactions between the enterprises and their external environment [5].

There are few people conducting research on enterprise niche composition. For example enterprise niche was classified into six dimensions by Wan, these included enterprise manufacturing capability, core technology competence, interface management ability, strategic management ability, core marketing competency, and learning creativity. Every dimension sets a series of second indices and weightings to reflect the competitiveness of the enterprise niche [12]. Combining these with system and catastrophe theory, Gao et al. established an enterprise niche evaluation index system with four factors, including demand, resource, technology and institution, with each factor requiring a series of sub-factors to reflect the status of the enterprise niche [13].

2.3. Literature review on wind turbine manufacturing industry

Electrical energy production has generally been derived from sources that are now becoming very limited. Because fossil fuel sources have a limited life span studies on electrical energy production involving renewable sources (such as hydrological, solar, wind, biomass and geothermal) are expanding as are concurrent studies dealing with energy savings [14]. With the world wide rapid development of wind power generation research on the wind turbine manufacturing industry has been attracting significant global attention. From the perspective of the wind turbine manufacturing industry, Linda et al. reviewed the development of the wind turbine manufacturing industry in Denmark and the Netherlands and analyzed the different development status between the countries [15]; Joanna examined wind turbine development in India and China, and the technology development strategies that had been pursued by Suzlon and Goldwind, India's and China's leading wind turbine manufacturing companies [16]; He and Chen reviewed the status of wind turbine generator system manufacturing and discussed the problems of the supply chain in China from a macroscopic point of view [17]; Zhao et al. reviewed the performance of wind power industry development in China and analyze the wind turbine manufacturing briefly [18]; Yu and Qu reviewed Chinese wind turbine manufacturers and carried out a brief analysis of the distribution of installed wind turbines [19].

In 2004, Linda et al. found that the difference in learning mechanisms led to the different development status of the wind turbine

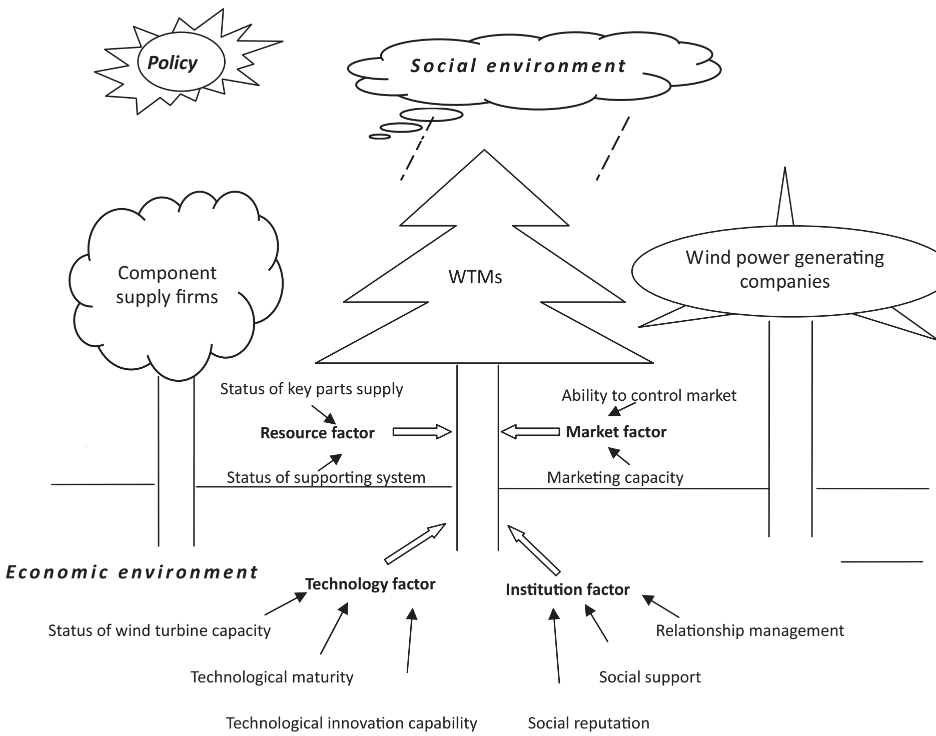

Fig. 1. Wind turbine manufacturing industry ecosystem model.

manufacturing industry in Denmark and Netherlands from the perspective of innovation systems, and concluded that the learning that results from the interaction between turbine producers and turbine users was the key to why Denmark had developed a large and thriving wind turbine manufacturing industry [15]; Joanna and Ryan explored the "motivations behind establishing a local wind power industry and the paths that different countries had taken to develop indigenous large wind turbine manufacturing industries though a cross-country comparison of the policy support mechanisms", and concluded that a manufacturer's success in its home country market would likely depend in part on its eventual success in the global wind power market [20].

These researches explored the existing and developing situation of the wind turbine manufacturing industry predominantly from a macroscopic view. Clearly there is a real need for further and detailed research in this area.

3. Wind turbine manufacturing industry ecosystem

According to the enterprise niche theory and the research literature [10–13], the wind turbine manufacturing industry ecosystem can be defined as a dynamically balanced system, where WTMs, supply and demand entities, and their external environment (involving social, economic and policy) derives from the interaction and interdependency amongst all the related entities under certain time and space conditions. Fig. 1 indicates a wind turbine manufacturing industry ecosystem model that represents this.

The wind turbine manufacturing industrial chain consists of three entities: WTMs, Wind turbine component supply firms and wind power generating companies; collectively these entities promote the development of the wind turbine manufacturing industry in China.

- The existing and future situation of WTMs depends to a large extent on the composition of the enterprise niche market. Identifying the composition of the WTMs' ecological niche is therefore a key factor in the analysis of WTMs' existing status and the development trends in the Chinese wind turbine market. In the model depicted in Fig. 1 above, the WTM is represented by a tree and the WTM' ecological niche consists of four ecological niche factors, namely a market factor, a resource factor, a technology factor and an institution factor, that enable the WTM and the external environment to interact. The external environment where the wind turbine manufacturing industry is located involves the social environment, the economic environment and the policy environment. These are represented by clouds, soil and sunlight. Through the analysis of the WTMs' ecological niche composition, the market factor involves two sub-factors, i.e. the ability to control the market, and marketing capacity. The resource factor involves two sub-factors, i.e. the status of key components supply and the status of the supporting system. The technology factor involves three sub-factors, i.e. status of wind turbine capacity, technological maturity and technological innovation capability. Finally the institution factor involves three sub-factors, i.e. relationship management, social support, and social reputation.

4. WTMs' ecological niche evaluation index system

This research has led to the design and establishment of a WTMs' Ecological Niche Evaluation Index System (WENEIS) according to the following principles:

1. *Scientific credibility*: In order to guarantee the scientific credibility of the WENEIS design, the authors reviewed and referred to the existing research literature and results including the seminal work of Truman and Anderson, Guo and Xu [21–23].
2. *Repetition avoidance*: The number and appropriateness of WENEIS index factors are important in evaluating the WTMS' ecological niche status. An excessive number of index factors are a disadvantage when distinguishing the index category and the importance of various factors. Thus, the WENEIS design should strive to avoid any unnecessary repetition.

Table 1
WTMs' ecological niche evaluation index system.

Target layer	Rule layer	Schematic layer	Score evaluation method
1. Market factor	1.1 Ability to control market	1.1.1 Market share	According to the WTM's accumulative installed wind turbines capacity and giving dimensionless evaluation
		1.1.2 Number of factories	According to the WTM's factory number and giving dimensionless evaluation
		1.1.3 Cooperative relationship between WTM and wind power generating companies	Cooperative relationship between the WTM and the wind power generating companies: 1.0 □ Long term strategic integration relationship between the WTM and wind power generating company 0.75 □ Partnership between the WTM and wind power generating company 0.5 □ Temporary supply and demand relationship between the WTM and wind power generating company
	1.2 Marketing capacity	1.2.1 Market extension ability	According to the WTM's newly installed wind turbines in 2009 and giving dimensionless evaluation
		1.2.2 Market flexibility ability	According to the WTM's flexibility ability to market changes: 1.0 □ Very strong flexibility ability to deal with the market and demand changes 0.75 □ Strong flexibility ability to deal with the market and demand changes 0.5 □ Average flexibility ability to deal with the market and demand changes
2. Resource factor	2.1 Status of key components supply	2.1.1 Status of bearings supply	According to the status of the bearings supply: 1.0 □ The WTM can develop and produce the bearings independently 0.75 □ Partnership between the WTM and international bearings manufacturers 0.5 □ Supplied by domestic bearings manufacturers only
		2.1.2 Status of control system supply	According to the status of control system supply: 1.0 □ The WTM can develop and produce the control system independently 0.75 □ Partnership between the WTM and international control system suppliers 0.5 □ Supplied by domestic control system suppliers only
	2.2 Status of supporting system	2.2.1 Components production capacity	According to the status of components production capacity: 1.0 □ The WTM can produce key components independently 0.75 □ The WTM can produce partial key components independently 0.5 □ The WTM can produce non-key components only
		2.2.2 Industries completing status in WTM's location	According to the industries completing and matching status in WTM's location area 1.0 □ The WTM located in the wind turbine components manufacturing centralized zone 0.75 □ The WTM near the wind turbine components manufacturing centralized zone 0.5 □ Only a few wind turbine components manufacturers near the WTM
3.Technology factor	3.1 Status of wind turbine capacity	3.1.1 Types of MW-scale wind turbines	According to the products types of MW-scale wind turbines and giving dimensionless evaluation
		3.1.2 Production capacity of 1.5 MW wind turbines	According to the production capacity of 1.5 MW wind turbines and giving dimensionless evaluation
	3.2 Technology maturity	3.2.1 Manufacture technology level of 1.5 MW wind turbine	According to the technology level of manufacturing 1.5 MW wind turbine: 1.0 □ International advanced technologies 0.75 □ International mature technologies 0.5 □ Domestic mature technologies
		3.2. Learning ability produced by new technologies	According to the WTM's new technologies learning and absorbing ability: 1.0 □ The learning ability is very strong 0.75 □ The learning ability is relatively strong 0.5 □ The learning ability is average
	3.3 Technological innovation capability	3.3.1 Number of research and development professionals	According to the number of research and development professionals and giving dimensionless evaluation
		3.3.2 Types of MW-scale wind turbines by independent research and development	According to the types of MW-scale wind turbines through the WTM's independent research and development and giving dimensionless evaluation

Table 1 (*Continued*)

Target layer	Rule layer	Schematic layer	Score evaluation method
4. Institution factor	4.1 Relationship management	4.1.1 WTM's legal status	According to the WTM's ownership types: 1.0 □ State-owned enterprise 0.75 □ Joint venture enterprise 0.5 □ Private enterprise
		4.1.2 WTM's financing ability	According to the WTM's financing ability: 1.0 □ Financing channel is multiplex and financing ability is very strong 0.75 □ With a few financing channel and financing ability is strong 0.5 □ Financing channel is few and financing ability is average
	4.2 Social support	4.2.1 Supports by the laws and policies	According to the supports by the laws, regulations and policies of the country: 1.0 □ Strong support to the development of wind turbine manufacturing industry 0.75 □ Support to the development of wind turbine manufacturing industry 0.5 □ Average to the development of wind turbine manufacturing industry
		4.2.2 Support by the local government	According to the support and encouragement by the local government 1.0 □ Strong support to the development of wind turbine manufacturing industry 0.75 □ Support to the development of wind turbine manufacturing industry 0.5 □ Average to the development of wind turbine manufacturing industry
	4.3 Social reputation	4.3.1 WTM's performance ranking	According to the WTM's past performance and achievement ranking and giving dimensionless evaluation
		4.3.2 WTM's goodwill	According to the WTM's brand value and goodwill: 1.0 □ Brand value and goodwill is very good 0.75 □ Brand value and goodwill is good 0.5 □ Brand value and goodwill is average

3. *Objectivity of feasibility and availability*: In the process of the WENEIS design, we strive to use an objective approach wherever possible.

According to the above principles, a WENEIS is constructed as shown in Table 1. This is based on two types of Wind Turbine scales namely those in the kW range and those in the MW range.

5. Local Chinese WTMs' ecological niche evaluation

5.1. Sample selection

According to the ranking of Local Chinese WTMs' accumulative installed wind turbine capacity until 2009 [3], the top 6 local Chinese WTMs were selected as the evaluation samples as shown in Table 2.

Table 2
Top 6 local Chinese WTMs' accumulative installed capacity and percent until 2009.

Companies	Installed capacity (MW)	Percent of total capacity (%)
Sinovel Wind Group Co., Ltd. (Sinovel)	5652	21.9
Goldwind Science and Technology Co., Ltd. (Goldwind)	5351	20.7
Dongfang Electric Machinery (DEC)	3329	12.9
Guangdong Mingyang Wind Power Turbine Manufacture Co., Ltd. (Mingyang)	896	3.5
United power Technology Co., Ltd. (United Power)	792	3.1
Zhejiang Windey Engineering Co., Ltd. (Windey)	594	2.3
Total	16,614	64.4

5.2. Investigation and review of the 6 main local Chinese WTMs

5.2.1. Market factor

5.2.1.1. Ability to control market. The authors' research indicates that the current production capacity of WTMs in China suggests that WTMs can be classified according to the following three types: (1) Large WTMs, with a cumulative installed capacity of more than 2000 MW (until 2009), including Sinovel, Goldwind, and DEC, with their total cumulative installed capacity of 55.5% of the total installed wind turbine capacity. (2) Medium-sized WTMs, with a cumulative installed capacity of less than 1000 MW, such as Mingyang, United Power, and Windey, with their cumulative installed capacity being 8.9% of China's total installed wind turbine capacity. (3) Small-sized WTMs, during the phase of prototype turbine testing.

From a strategic perspective, most of the local Chinese WTMs factories were located in regions near the Chinese main wind energy resource zones and (or) the wind turbine components and accessories manufacturing industry centralized zones. For example, until the end of 2009, Sinovel established its factories in throughout China in Dalian, Yanchang, Baotou, Jiuquan, Dongying and Baicheng. Goldwind located its factories in Beijing, Chengde, Urumqi (2 factories), Baotou, Yinchuan, Jiuquan, Xi'an and Dafeng. DEC located its factories in Tianjin, and Deyang. United Power located its factories in Baoding, Lianyungang, Chifeng and Jiuquan. Windey established its factories in Hangzhou and Zhangjiakou. However the smallest WTMs had no factories located outside of their headquarters.

5.2.1.2. Marketing capacity. The researchers' investigations revealed that in 2009 Sinovel, Goldwind and DEC had achieved a newly installed capacity of 3495 MW, 2722 MW, and 2035.5 MW, respectively during which the total newly installed capacity of the three companies for that year was 59.7% of the total Chinese newly

Table 3
The selected local Chinese WTMs' newly installed capacity in 2009.

Companies	Newly installed capacity (MW)	Percent of total newly installed capacity (%)
Sinovel	3495	25.3
Goldwind	2722	19.7
DEC	2035.5	14.7
United Power	768	5.6
Mingyang	748.5	5.4
Windey	260.75	1.9
Total	10029.75	72.6

installed capacity. The other local Chinese WTMs were far behind the big three companies, and not one of their newly installed capacity exceeded 800 MW in 2009. Similarly, there were 16 local Chinese WTMs whose newly installed capacities fell between 100 MW and 800 MW, with their total newly installed capacity achieving 36.3% of the total Chinese newly installed capacity in 2009. There were also more than 20 local Chinese WTMs whose newly installed capacities were less than 100 MW, with their total newly installed capacity achieving 4% of the total Chinese newly installed capacity for that year with most of those companies being involved in prototype turbine testing and installation.

Table 3 indicates the installed capacity for the 6 investigated local Chinese WTMs [3].

5.2.2. Resource factor

5.2.2.1. Status of key components supply. The investigations found that the number of manufacturers, who were able to produce key components and accessories of wind turbine generation units (including wind turbine blades, gearboxes, bearings, generators and electrical control system), are gradually increasing. The localization of manufacture of the major accessories for the wind turbines in the kW range or scale means that they can now be supplied in large quantities. There are, however, still large gaps in the manufacture of key components for the wind turbines above the MW-scale. Most Chinese WTM factories cannot manufacture some key components (such as the blades, bearings, and electrical control systems) for the 2 MW wind turbines. Taking bearings as an example, the interviews revealed that there are three main ways to deal with this issue, i.e.: (1) Where the Chinese industry (WTMs) decides to research, develop, design and manufacture the bearings independently, as do DEC and Windey; (2) to import the components or to establish a partnership with a foreign supplier, for example, Sinovel and Goldwind have both established long-term strategic partnerships with the world largest bearings supplier the SKF Group; (3) to purchase from Chinese domestic bearings manufacturers, as do the majority of the medium and small-sized WTMs.

5.2.2.2. Status of supporting system. The investigation statistics indicate that, there were at least 52 blade manufacturers, 16 bearings manufacturers, 10 gearbox manufacturers, and 12 converter manufacturers who supply wind power components in the Chinese market. As of 2008, components that were made in China could meet 90% of the domestic demand for 600 kW or 750 kW models, while they could only meet 70% of the market for the 1.5 MW units. Unfortunately, the output of China's component and accessories manufacturing could not meet the actual Chinese market demand. For example bearing and flanges are necessary components but few manufacturers could produce them. The production cycle of some components and accessories is complex and requires a long production cycle. Given that the components supply cannot keep up with demand and that there is a long lead time to supply these components the importing of components from overseas is the only current guaranteed method of meeting the demand in the Chinese market.

Table 4
The selected Local Chinese WTMs' 1.5 MW wind turbine production capacity by the end of 2009.

Companies	Production capacity (units)
Sinovel	2400
Goldwind	1391
DEC	1200
Mingyang	470
United Power	600
Wingdey	150

As the survey of the 6 local Chinese WTMs revealed, Sinovel and DEC can produce most key components such as blades and gearboxes; Goldwind can produce a few key components, including converters, etc., whereas United Power, Windey and Mingyang can produce some minor components and accessories, and most key components are purchased from other manufacturers. Although the Chinese WTMs' ability to produce key components has improved, the bottleneck for the wind turbine manufacturing industry in China is still that the key components need to be imported from foreign suppliers. Against this background it should be noted that there has been continuous improvement in both the technology and quality of the key component and accessory production of wind turbines in China.

5.2.3. Technology factor

5.2.3.1. Status of wind turbine capacity. In order to develop and improve production capacity of the Chinese market some top Local Chinese WTMs have developed their own design for the wind turbines and the manufacturing technology process for the 600 kW, the 750 kW, and the 800 kW turbines. The investigations revealed that the MW-scale wind turbine is becoming the most in demand product type in the Chinese wind turbine market. By using independent research and development (R&D) or by importing foreign technologies, some local Chinese WTMs have now become capable of mass producing the MW-scale wind turbines including the 1.25 MW, the 1.5 MW, and the 2.0 MW models. An example of this is the 1.5 MW wind turbine which (as a major product) reached a 67% share of the Chinese market by 2009. Table 4 indicates the production capacity (of the 6 local WTMs that formed part of this study) that had been achieved by the end of 2009 for the 1.5 MW wind turbines [3].

5.2.3.2. Technology maturity. Currently, the design and production of 1.5 MW wind turbines for local Chinese WTMs can be done in three different ways, i.e. (1) By purchasing foreign (advanced) wind power technology and signing technology transfer contracts with foreign enterprises in order to obtain 1.5 MW production licenses in China. This approach has been used by Goldwind Sinovel, DEC and Mingyang; (2) By importing developed design drawings and technologies from foreign firms or by collaborating with foreign wind turbine design firms. In this latter approach the foreign design firms undertake and supply the design documentation, while the local Chinese WTMs undertake equipment processing, manufacturing and sales. An example of this is United Power; (3) By using their own independent R & D and existing experience and technologies. An example of this is Windey.

The current strategy of Chinese WTMs is to improve their turbine manufacturing ability by adopting mature foreign technologies while at the same time trying to produce as many key components and accessories as possible in the domestic market. Most Chinese enterprises are having difficulty coming to grips with the key technology essential for wind turbine design and manufacture and this is proving to be a real barrier to the development of the wind power generation industry in China.

5.2.3.3. Technological innovation capability. The human resource structures of most local Chinese WTMs are different from one another. The number and level of R&D personnel has a significant effect on an enterprise's R&D ability and eventual achievements. China's Ministry of Science and Technology has funded the R&D of large wind turbine schemes and has supported local Chinese WTMs seeking to gain a competitive advantage position to successfully enter the market. It should be noted that China has become more competitive in the wind turbine market and is now one of only a few countries capable of mass production. As the production capacity of both domestic and foreign manufacturers continues to increase, and with more than 20 enterprises now investing in local R&D, it is expected that there will be a major increase in wind turbine production and capacity in the near future. From a Technical perspective, the Chinese wind power market is dominated by the established international technology-adjustable pitch and variable speed turbines. Early in April 2005, Goldwind had developed the 1.2 MW direct drive turbine, and had its power curve tested and approved by an international assessment agency. Under the Chinese government "863 Programme" of the Ministry of Science and Technology, the Energy Department of Shenyang Industry University succeeded in Researching and developing an adjustable pitch and variable speed double feed turbine of 1 MW capacity. In 2006, a 1.5 MW version of the same unit was developed and used in the Chinese wind power generation market. Meanwhile, both DEC and Sinovel had introduced adjustable pitch and variable speed technology and had produced large scale turbines that are operating in wind farms. The level of R&D in China is still improving and China has taken part in many international R&D activities to further accelerate this process. Up to the end of 2010, 3 MW wind turbines developed by Goldwind have been commissioned on a trial basis, while the 2.5 MW wind turbines are reducing in numbers being produced. Similarly, 3 MW offshore wind turbines developed by Sinovel were connected to the power grid in Donghai bridge wind farm. Additionally, Goldwind, Sinovel, DEC and other companies have started to develop large-scale wind turbines, including wind turbines with single-machine capacity 5 MW.

5.2.4. Institution factor

5.2.4.1. Relationship management. The wind turbine manufacturing industry is a technology and capital intensive industry. By the end of 2009, in China, there were 82 WTMs involving 39 state-owned firms, 24 private firms, 9 joint ventures and 10 foreign owned firms. Of the top 6 local Chinese WTMs that we selected to study, Sinovel, Goldwind, DEC, United Power, and Wingdey are state-owned enterprises or state-holding enterprises, and Goldwind and DEC are listed companies; only Mingyang is a private enterprise.

5.2.4.2. Social support. The wind turbine manufacturing industry affects the development of the Chinese wind power generation industry, hence the Chinese government attaches significant importance to how the progress of the local Chinese WTMs. This was evidenced in 2009 when President Hu Jin-tao and Chairman of the Standing Committee of the National People's Congress Wu Bang-guo visited Goldwind and Sinovel, respectively. More recently, the Chinese government has been formulating integrated laws and regulations to actively encourage the development of the wind turbine manufacturing industry. An example of this has been the introduction of restrictive electric power pricing to encourage investment in wind power and support for wind power equipment manufacturing.

5.2.4.3. Social reputation. As the essential core component, wind turbines have a significant effect on the long term stability and operation of the wind power system. Both goodwill and performance over time play a key role in the selection of WTMs for wind power generating companies. In many ways the wind turbines are a reflection of product quality, performance capability, operation and maintenance ability, and service life. In 2009, several local Chinese WTMs began to export their products to other countries; namely Sinovel and Goldwind exported ten 1.5 MW wind turbine units to India; Goldwind exported three 1.5 MW wind turbine units to the USA. This foray into the world market is now allowing local Chinese WTMs to enhance their brands, goodwill and performance experience in many parts of the world.

5.3. Values

The statistical data for the research has generally been sourced from: (1) Interviews with wind power experts, (2) The Chinese Wind Energy Association [24], (3) The Chinese Clean Energy Network [25], (4) The WTMs' Annual Reports, as well as (5) The WTMs' web sites [26–29].

The initial data was then transformed to the dimensionless form values between 0 and 1 as indicated in Table 5. This was done by using the following formula

$$y_i = \frac{x_i}{\max x_i} \quad i \text{ is sample size} \tag{1}$$

Hence, the influence arising from different dimensions of indexes to the following calculation can be eliminated.

5.4. Calculation

The Catastrophe theory is a branch of mathematics that arose in the 1950s and 1960s. The comprehensive evaluation of the object using the catastrophe theory is to breakdown the evaluation object into multi-layers, and then uses the mutation fuzzy subjection functions that are produced by the integration of catastrophe theory and fuzzy mathematics and the general formulae to calculate and ultimately obtain a parameter index. There are four common mutation models as shown in Table 6 [30].

The WTMs' ecological niche indexes including market factor, resource factor, technology factor and institution factor have the characteristics of order-parameter [31,32], which can be used to comprehensively evaluate the enterprise niche by mutation functions. In multi-objective decisions, researchers generally use Analytic Hierarchy Process (AHP), Utility Function, or Fuzzy Membership Function. However, owing to the complex relationships amongst the various indexes, it is often difficult to judge the indexes' weightings, and sometimes people judge them by using subjective decisions. This subjective approach makes it difficult to use AHP, Utility Function or Fuzzy Membership Function analysis. By contrast, the Mutation evaluation method absorbs the advantages of AHP and Fuzzy Evaluation. And the indexes weightings, are determined by the inner contradictions and logical relationships in various control variables, with little subjectivity. The catastrophe theory evaluation method conducts operations according to the computational formula and decision rule deduced by the mutation models, and thereby reduces the volume of computation. Moreover, this method just needs to consider the order of indexes' importance [33]. Consequently, the mutation evaluation method is a simple and practical method, especially suitable for multi-objective decision.

Using the general formulae as shown in Table 6, we can obtain the evaluation parameter of the enterprise niche calculating from the bottom of the inverse tree hierarchy. Since there are some complementary influences between the middle and bottom indexes in the model, we can calculate the value of x by calculating their

Table 5
Data of the WTMs' ecological niche factor indexes.

Target layer	Rule layer	Schematic layer	Sinovel	Gold-wind	DEC	Ming-yang	United Power	Windey
Market factor	Ability to control market	Market share (%)	21.9	20.7	12.9	3.5	3.1	2.3
		Number of factories	6	9	2	5	4	2
		Cooperative relationship between WTMS and wind power generating companies	1	1	0.75	0.5	0.5	0.5
		Score	0.889	0.982	0.52	0.405	0.362	0.276
	Marketing capacity	Market extended ability (%)	25.3	19.7	14.7	5.4	5.6	1.9
		Market flexibility ability	0.75	1	1	0.75	0.5	0.75
		Score	0.875	0.89	0.79	0.51	0.36	0.44
Resource factor	Status of key components supply	Status of bearings supply	0.75	0.75	1	0.5	0.5	1
		Status of control system supply	0.75	1	0.75	1	1	0.5
		Score	0.75	0.875	0.875	0.75	0.75	0.75
	Status of supporting system	Components production capacity	1	0.75	1	0.5	0.5	0.5
		Industries completing status in WTMs' location	1	0.75	1	0.5	0.5	0.5
		Score	1	0.75	1	0.5	0.5	0.5
Technology factor	Status of wind turbine capacity	Types of MW-scale wind turbines	3	3	2	2	3	2
		Production capacity of 1.5 MW wind turbines	2400	1391	1200	470	600	150
		Score	1	0.848	0.635	0.453	0.65	0.373
	Technological maturity	Manufacture technology level of 1.5 MW wind turbine	1	1	1	1	0.75	0.5
		Learning ability produced by new technologies	1	1	0.5	0.75	0.75	1
		Score	1	1	0.75	0.875	0.75	0.75
	Technological innovation capability	Number of research and development professionals	300–400	500–600	400–600	100–200	50–100	70–100
		Types of MW-scale wind turbines by independent research and development	1	2	0	1	1	1
		Score	0.568	1	0.455	0.387	0.568	0.328
Institution factor	Relationship management	WTMs' legal status	1	1	1	0.5	1	1
		WTMs' financing ability	0.75	1	1	0.5	0.75	0.75
		Score	0.875	1	1	0.5	0.875	0.875
	Social support	Supports by the laws and policies	1	1	1	1	1	1
		Support by the local government	1	1	1	1	1	1
		Score	1	1	1	1	1	1
	Social reputation	WTMs' performance ranking	9	10	8	6	7	5
		WTMs' goodwill	0.75	1	0.5	1	0.5	0.75
		Score	0.825	1	0.65	0.8	0.6	0.625

average. Take the enterprise Sinovel as an example, its mutation model is shown as Fig. 2. The bottom of the model is the dimensionless values of the initial data to niche indexes, then the values of x_1, x_2, x_3, x_4 can be calculated upwards using the general formulae until we finally obtain the evaluation parameter X of the enterprise niche.

x_1, x_2 is a spire form mutation function, and according to the general formula (3) in Table 6, we can get that $x_{1-1} = \sqrt{u} = \sqrt{0.889} = 0.943$, $\quad x_{1-2} = \sqrt[3]{v} = \sqrt[3]{0.875} = 0.956$Then calculate the average value according to the principle of the mutual complementarities:

$$x_1 = \frac{x_{1-1} + x_{1-2}}{2} = 0.950;$$

Similarly to x_1, x_2 is also a spire mutation function, using above method, we can calculated that $x_2 = 0.933$; x_3, x_4 is a coattail mutation function, and according to the general formula (4) in Table 6, we can get $x_{3-1} = x_{3-1} = \sqrt{1} = 1$, $\quad x_{3-2} = \sqrt[3]{v} = \sqrt[3]{1} = 1$, $\quad x_{3-3} = \sqrt[4]{w} = \sqrt[4]{0.568} = 0.868$

Then calculate the average value according to the principle of the mutual complementarities:

$$x_3 = \frac{x_{3-1} + x_{3-2} + x_{3-3}}{3} = 0.956;$$

Similarly to x_3, x_4 is also a coattail mutation function, we can calculated that $x_4 = 0.963$;

Table 6
Four common mutation models.

Mutation type	Control variable	Status variable	Mutation function	General formulae	
Folded	1	1	$f(x) = x^3 + ux$	$x_u = \sqrt{u}$	(2)
Spire	2	1	$f(x) = x^4 + ux^2 + vx$	$x_u = \sqrt{u}, x_v = \sqrt[3]{v}$	(3)
Coattail	3	1	$f(x) = x^5 + ux^3 + vx^2 + wx$	$x_u = \sqrt{u}, x_v = \sqrt[3]{v}, x_w = \sqrt[4]{w}$	(4)
Butterfly	4	1	$f(x) = x^6 + tx^4 + ux^3 + vx^2 + wx$	$x_u = \sqrt{u}, x_v = \sqrt[3]{v}, x_w = \sqrt[4]{w}, x_t = \sqrt[5]{t}$	(5)

Note: $f(x)$ = System potential function reflecting the status of the system, and the integration of status variable x and control variable u, w, v, t.

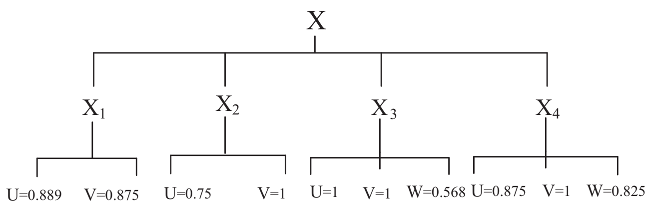

Fig. 2. Sinovel mutation evaluation system.

x is a butterfly mutation function, and according to the general formula (5) in Table 6, we can get that

$$x_u = \sqrt{u} = \sqrt{x_1} = \sqrt{0.950} = 0.972, \quad x_v = \sqrt[3]{v} = \sqrt[3]{x_2} = \sqrt[3]{0.933} = 0.977 x_u$$

$$x_w = \sqrt[4]{w} = \sqrt[4]{x_3} = \sqrt[4]{0.956} = 0.989, \quad x_t = \sqrt[5]{t} = \sqrt[5]{x_4} = \sqrt[5]{0.963} = 0.992 x_w$$

As the factors of the enterprise niche can affect the enterprise niche directly and independently and their complementary relationship is relatively small. Thus, according to the Fuzzy Theory, the top index x is the minimum amongst x_u, x_w, x_v, x_t. So the parameter x of Sinovel is

$$x = \min[x_u, x_w, x_v, x_t] = x_u = 0.972;$$

Similarly, we can get the ecological niche evaluation parameters of the other 5 WTMs accordingly:

Goldwind $x = 0.982$, DEC $x = 0.907$, Mingyang $x = 0.847$, United Power $x = 0.810$, and Windey $x = 0.802$.

According to above calculation results, the status of the enterprise niche for Sinovel and Mingyang as examples can be shown as a spider diagrams in Fig. 3. Comparing to Mingyang, Sinovel is a large state-holding enterprise with long-term experience in machine manufacturing. Sinovel has the competitive advantages in terms of both manufacturing and marketing, and these mainly attributes to the fact that Sinovel entered the wind energy market much earlier, possesses sufficient experienced professionals in wind power technologies, and has secured more wind power projects in China. These favorable conditions contribute to the Sinovel's advantages over Mingyang. Despite some weaknesses are existed in competing with Sinovel, Mingyang has been recognized for the strong R&D capabilities and excellent performance and reliability, and this reputation has given Mingyang substantial and sustainable impetus in the local market.

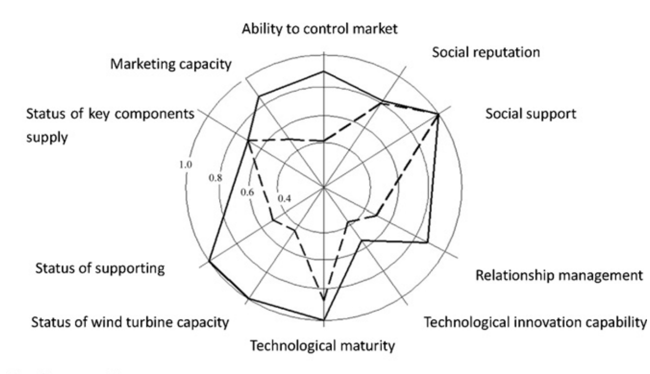

Fig. 3. Spider diagrams of ecological niche status for Sinovel's and Mingyang.

5.5. Results analysis

From the above calculation, we can deduce that Goldwind's various indexes score are average and relatively higher, thus achieving the highest niche evaluation parameter score; Sinovel and DEC's "ability to control the market" is weaker than that of Goldwind and limits the Sinovel's development of the market factor; The fact that Mingyang, United Power and Windey's final parameters fall behind are mainly attributed to the weaker "ability to control market" and "marketing capacity", which limits the development of market factor. We also find that the weak market factor and technology factor in WTMs' ecological niche are the two main factors that disadvantage the future of local Chinese WTMs.

Comparing the ecological niche evaluation results for the 6 selected local Chinese WTMs, on the Spider diagram we can better understand the relationship between the local Chinese WTMs manufacturers coordination capability with their external market environment. Thus, the existing situation and future direction of local Chinese WTMs in the wind turbine manufacturing industry can be estimated reasonably accurately. Moreover, according to the various indexes score, we can determine the gap amongst the 6 investigated local Chinese WTMs through the spider diagram. Accordingly it is possible to estimate the competitive advantages and disadvantages for the 6 selected local Chinese WTMs. The ecological niche evaluation carried out by the authors may therefore help local Chinese WTMs to determine their competitive strengths and weaknesses and to eliminate those weaknesses as part of their future development.

6. Conclusion

Using the enterprise niche theory, this paper has established a wind turbine manufacturing industry ecosystem model to demonstrate the relationship and interaction amongst the WTMs, components supply firms, wind power generating companies, as well as related social environment, economic environment, and policy environment. The proposed industry ecosystem model consists of market factor, resource factor, technology factor, and institution factor. The existing and development situation of WTMs can be comprehensively analyzed through the model. This paper also presents a WTMs' ecological niche evaluation index system (WENEIS), and puts forward WENEIS' three layer evaluation factors as well as their score evaluation method. Based on the investigation, interview and statistical data, the 6 main local Chinese WTMs were selected as a sample to evaluate their ecological niche index factors, and a catastrophe theory model evaluation method was used to calculate the results. The results indicate that the WENEIS are suitable to evaluate the coordinating ability between the WTMs and external environment, and are effective for WTMs' competitive advantages and disadvantages factors identification and strategy selection. In addition, the proposed industry ecosystem model and the ecological niche evaluation system have the potential to be applied to enterprise competitiveness study in other industries.

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